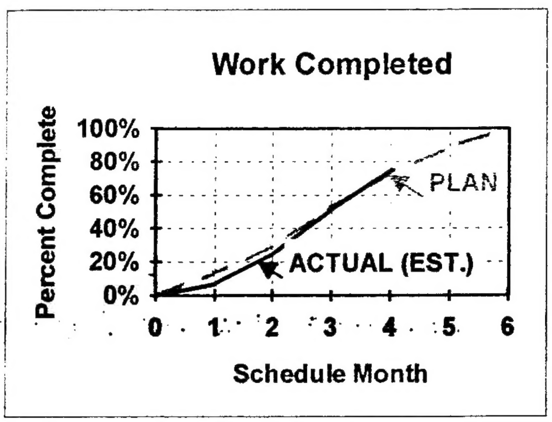
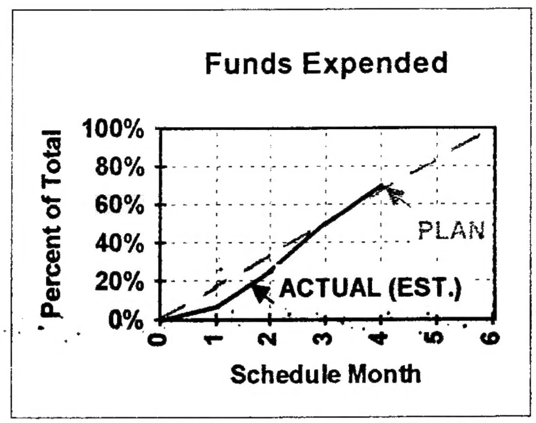
**Lumen**
Laboratories, Inc.  Lumen Laboratories, Inc. 170 Cambridge St. Burlington, MA 01803

# TECHNICAL PROGRESS REPORT #4

| | |
|---|---|
| **Contract No.:** | **N00014-95-C-0082** |
| Contract Type: | Phase I SBIR |
| Contract Title: | A High-Resolution Unconventional Imager for Missile Defense Applications |
| CLIN: | 0001AD |
| Submitted By: | Lumen Laboratories, Inc. (Cage Code: 01TU7) |
| Submitted To: | Dr. William Stachnik, ONR Program Officer (DoDAAD: N00014) |
| Date Submitted: | 1 May 1995 |
| **Report Period:** | **April 1995** |

| | | | |
|---|---|---|---|
| **Work Completed To Date (Est.):** | **75%** | **Funds Expended To Date (Est.):** | **70%** |
| **Planned Work Completed To Date:** | **73%** | **Planned Funds Expended To Date:** | **67%** |






## Summary of Technical Progress This Period

The program remains on schedule and within budget targets. The major accomplishments for this reporting period are summarized below by Statement of Work (SOW) task.

*Perform Top-Level Design Tradeoffs (SOW Item 1)* ***AND***
*Complete A Preliminary ASI Hardware Design (SOW Item 3)*

The bulk of the work for these tasks was completed previously and was summarized last reporting period. This period consideration was given to

commercial applications. <u>We have yet to identify a single commercial application where ASI will offer unique advantages.</u> As reported last period, ASI is well suited for imaging small (e.g. < 3 meter sized) targets at moderately long distances (e.g. 100 km in endo-atmospheric applications, > 100 km in exo-atmospheric scenarios). However, no commercial applications we have looked at require such capability. It is our belief that applications of shorter ranges (1 m - 10 km) can be handled more elegantly by conventional optics. The ASI requirement that the target be isolated in space so that the 1-D illumination stripe extends beyond the target on both sides further limits its utility in commercial schemes. In conclusion, it appears at this juncture that ASI will perform a class of military and space imaging tasks better than other known technologies, but it will not find commercial success. This point requires further discussion with the sponsor.

*<u>Investigate Image Quality Through Analysis and Simulation (SOW Item 2)</u>*

The bulk of this report is dedicated to this SOW task because of the significance of the results obtained in this area this reporting period.

The imaging performance of ASI has been modeled using the software tools illustrated in Figure 1. Lumen's MathCAD™-based ASI performance model was used to optimize system parameters like transmitter wavelength and aperture size, subaperture size and geometry, imaging field of view, etc. A baseline set of scenarios and appropriate targets were chosen from the strawman missions defined during the modeling work and discussions with outside groups familiar with military requirements. SPARTA's SENSORSIM™ sensor simulation environment was used to create scaled target models (simulated) and to calculate the speckle patterns that appear at the ASI subaperture array. Lumen Labs' custom-written, pc-based signal processing routines calculated the auto-correlation of each speckle pattern, processed the auto-correlation to determine its lobe width, reconstructed the ASI image from lobe width data and displayed the results.

Five targets were simulated and processed to evaluate ASI imaging performance. The target cases, along with pertinent system parameters for each case, are listed in Table 1. Note the range of simulation parameters used, especially the scope of target and image sizes. These variations were intentional, in order to explore the limits of ASI performance. The ideal (starting) target images are shown in Figure 2, as viewed from the ASI sensor viewing angle under white lights illumination conditions.

The ASI imager concept illuminates the target with a long, thin line of laser light in a step-wise fashion that passes from left to right across the target. At each illumination location the laser is pulsed and speckle intensity samples

are collected at the imager by the 1-D subaperture array. A speckle data vector is, therefore, generated from each illumination column location on the target. An example of a speckle data vector is plotted in Figure 3 as simulated from the mid-point on the delta wing of the fighter target model shown in Figure 2. The processing to recover ASI images from speckle patterns involves two computationally-simple steps. The first step calculates the auto-correlation of each speckle data vector. A typical result of such a computation in plotted in Figure 4. Note that the auto-correlation central (0-Lag) lobe width (e.g. its full width half maximum) scales linearly with the average speckle lobe size, which in turn scales inversely with the target width at the illumination stripe location. The second ASI image calculation step uses a local maximum/minimum finding routine to estimate the characteristic lobe widths present in the auto-correlation. Specifically, the average of all maximum and minimum peak spacings is calculated and inverted to determine the target width.

The ASI image simulation results are dramatic and very positive. Figures 5 through 9 show all data plotted in 2-D gray-scale format for the fighter aircraft, Tomahawk cruise missile, Learjet, intact SS-1B (SCUD) missile and damaged SCUD missile, respectively. In each case the ASI signatures are unique and easily interpreted to classify the starting target type. The exact target dimensions can easily be calculated and displayed by ASI software because exact scaling exists in image reconstruction and target range can be sensed using conventional laser radar circuits in conjunction with the pulsed ASI illuminator.

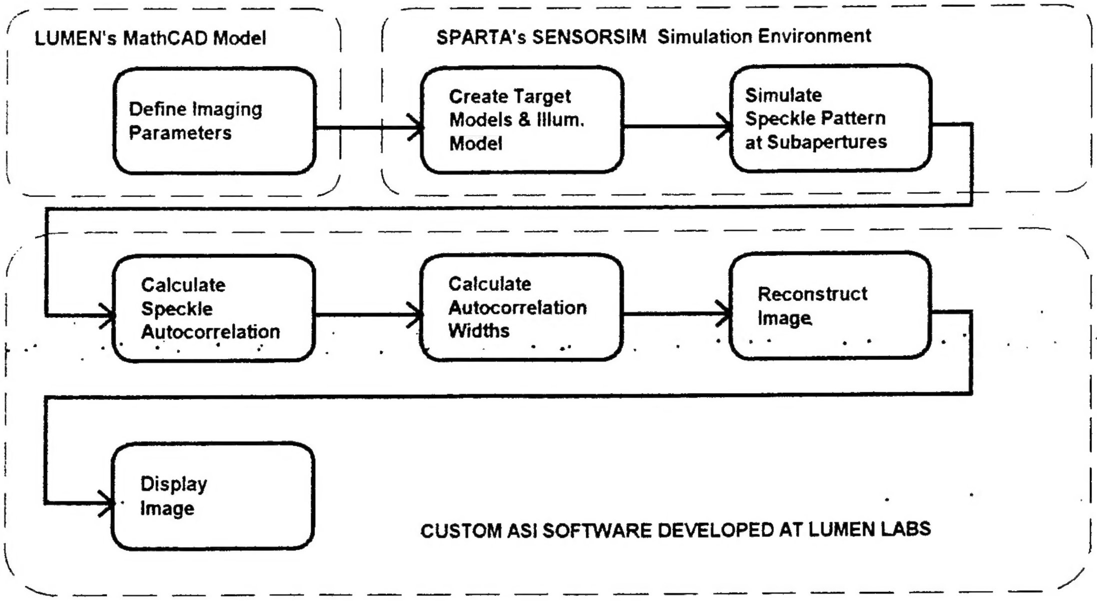
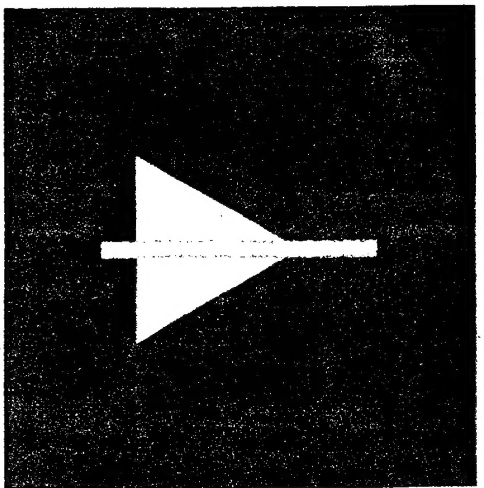


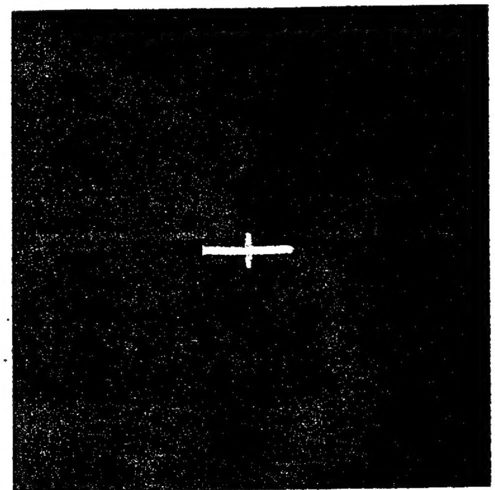

*Figure 1. Modeling Approach Used To Assess ASI Imaging Performance.*

*Table 1. Five Target Cases Used to Evaluate ASI Imaging Performance.*

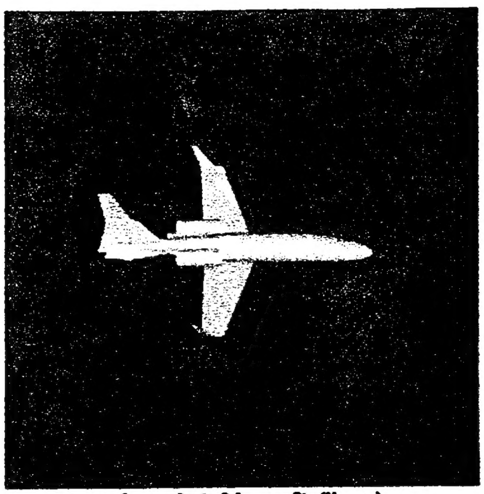
| Imaging Parameters | Fighter | Cruise Missile Tomahawk | Learjet Wide FOV | SS-1B (SCUD) Missile | SS-1B with Damage |
|---|---|---|---|---|---|
| Target Length | 15 m | 5 m | 15 m | 16 m | 16 m |
| Targ. Width (Max., Min) | 10, 1 m | 2, 0.5 m | 11, 1 m | 1.5, 0.6 m | 1.5, 0.6 m |
| Transmit Wavelength | 1.06 µm | 1.54 µm | 1.54 µm | 1.54 µm | 1.54 µm |
| Target Range | 50 km | 100 km | 100 km | 100 km | 100 km |
| Image Field of View (FOV) | 13 x 25 m | 5 x 20 m | 20 x 20 m | 5 x 20 m | 5 x 20 m |
| Acquisition (Illum.) FOV | 25 x 25 m | 10 x 20 m | 40 x 20 m | 10 x 20 m | 10 x 20 m |
| Image Size (Row, Col.) | 256 x 256 | 64 x 96 | 256 x 96 | 64 x 96 | 64 x 96 |
| Pixel Size (@ Targ) | 10 x 10 cm | 16 x 20 cm | 16 x 20 cm | 16 x 20 cm | 16 x 20 cm |
| Number of Subapertures | 256 | 64 | 256 | 64 | 64 |
| Subap. Array Size | 1 x 0.5 m | 1 x 0.4 m | 0.5 x 0.4 m | 1 x 0.4 m | 1 x 0.4 m |
| Transmit Aperture Size | 1 x .004 m | 1 x.016 m | 1 x .004 m | 1 x .016 m | 1 x .016 m |
| Speckle File Name | p_ftr1 | tom-01p | l31-01x | ss-1-01p | brk-01p |



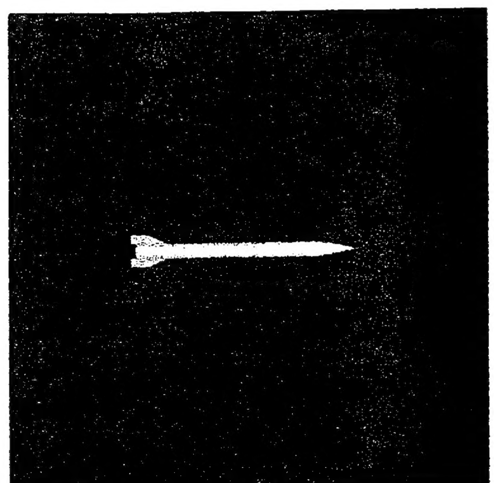
**Fighter Aircraft (iftr1)**



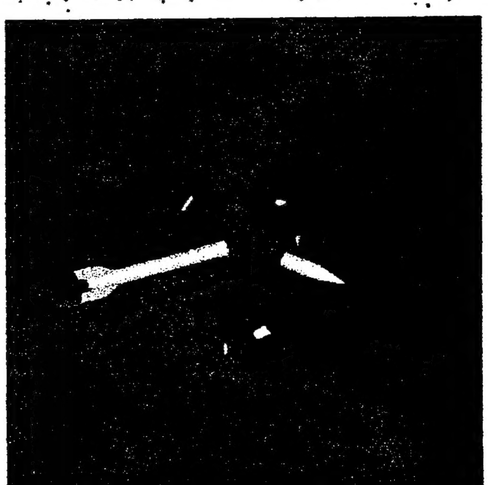
**Tomahawk Cruise Missile (itom)**



**Learjet Aircraft (ilear)**



**SS-1B (SCUD) Missile (iss1)**



**SS-1B (SCUD) Missile (Damaged) (ibrk)**

*Figure 2. Simulated Targets Used As Starting Inputs to Evaluate ASI Imaging Performance.*

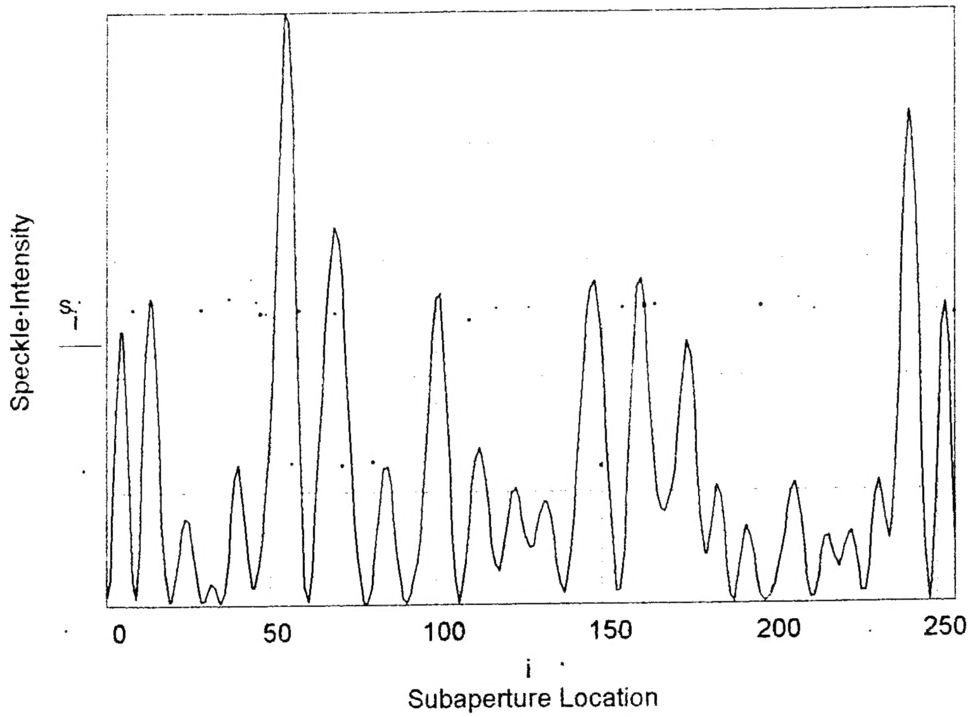



*Figure 3. Example of Speckle Intensity Data Vector Plotted Versus Subaperture Location. (Simulated at Mid-Point of Fighter Delta Wing Shown in Figure 2.)*

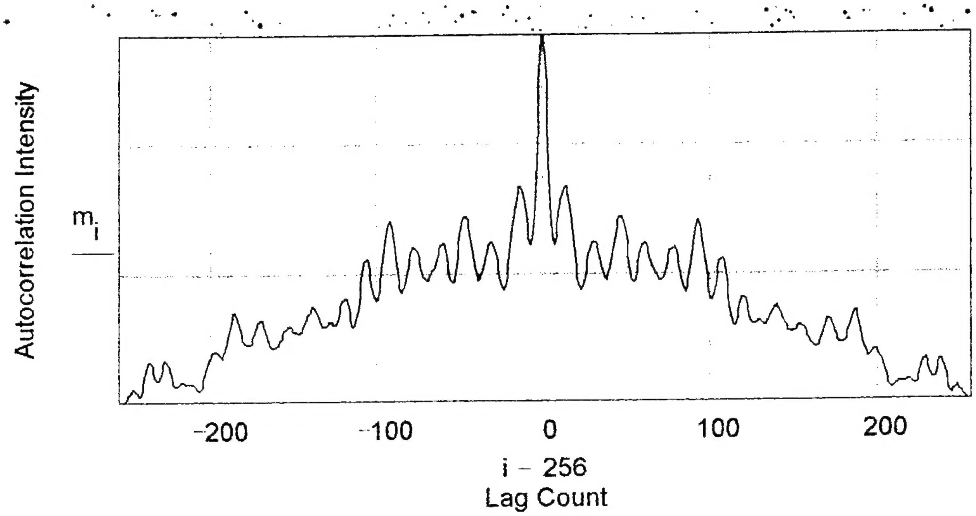
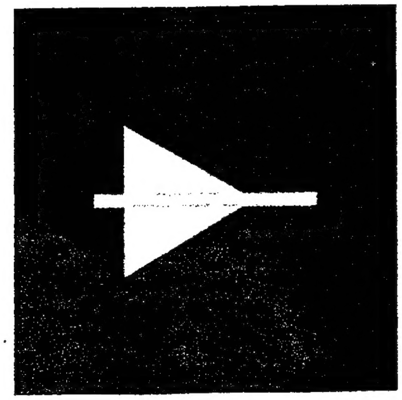
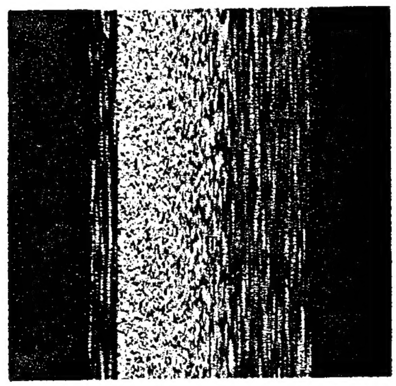



*Figure 4. Example of Auto-correlation of Speckle Data. (Calculated from Speckle Data Plotted in Figure 3.)*

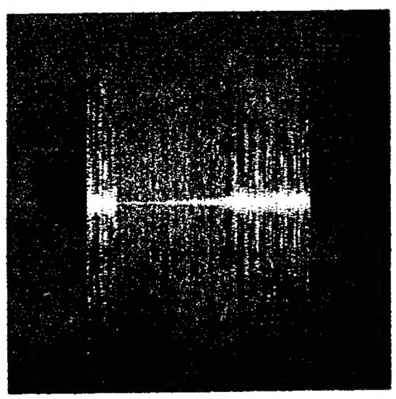
**Starting Image** (iftr1)



**Speckle Image** *(pftr1)*



**Auto-correlation** *(pftr1cor)*



**ASI Output Image** *(pftr1rec)*

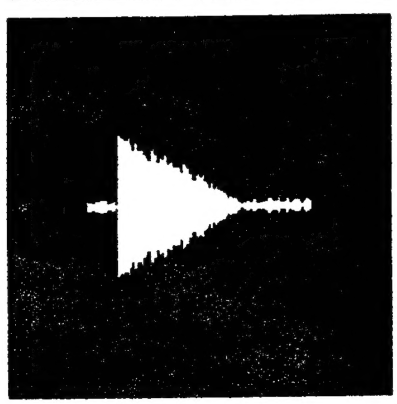
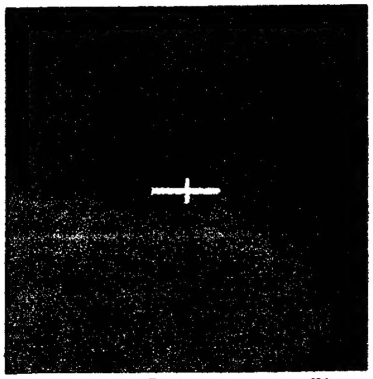
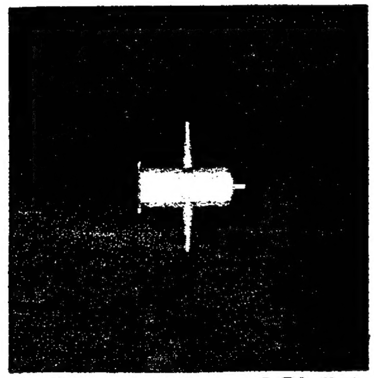


*Figure 5. Data and Reconstructed ASI Image Display for Fighter Aircraft (See Table 1.)*

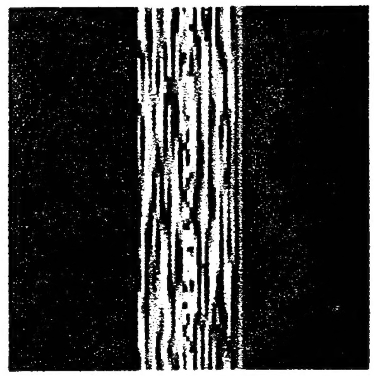


**Zoomed Out Image** *(itom1)*

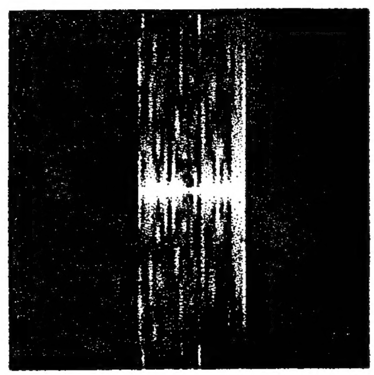


**As Viewed from ASI** *(ivtom1)*

**Speckle Image** *(pctom1)*



**Auto-correlation** *(ptom1cor)*



**ASI Output Image** *(ptom1rcp)*

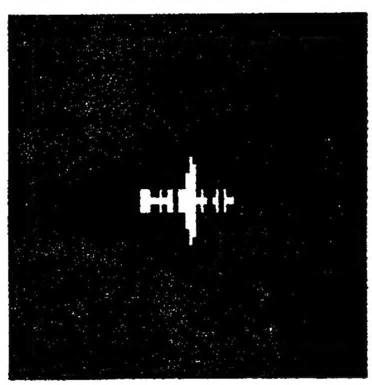
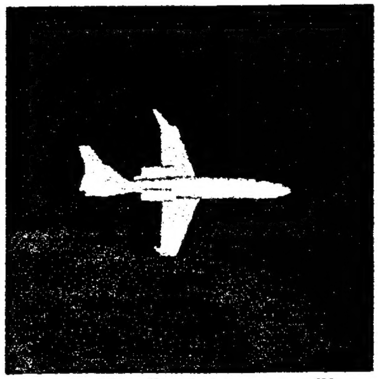
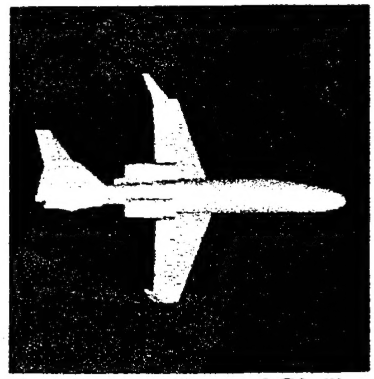


*Figure 6. Data and Reconstructed ASI Image Display for Tomahawk Cruise Missile (See Table 1.)*

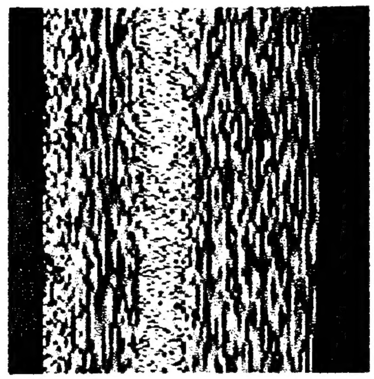


**Zoomed Out Image** *(ilear)*

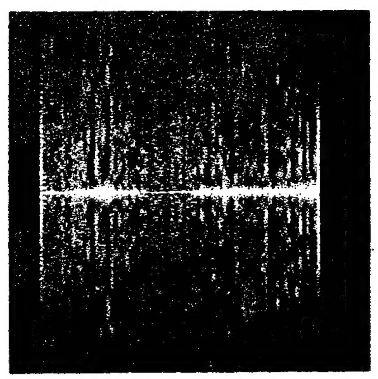


**As Viewed from ASI** *(ilearcrp)*

**Speckle Image** *(pcl31x)*



**Auto-correlation** *(pl31xcor)*



**ASI Output Image** *(pl31xrcp)*

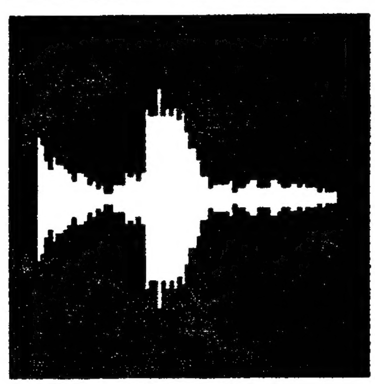
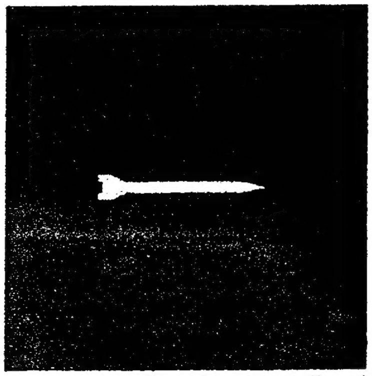
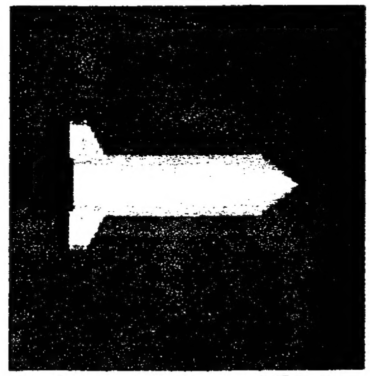


*Figure 7. Data and Reconstructed ASI Image Display for Learjet Aircraft (See Table 1.)*

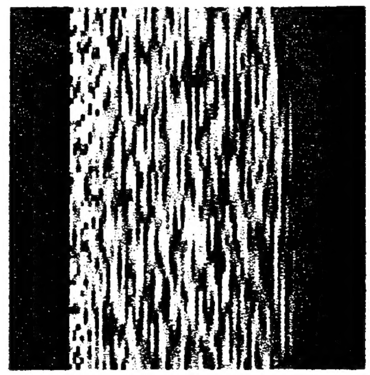


**Zoomed Out Image** ***(iss1)***

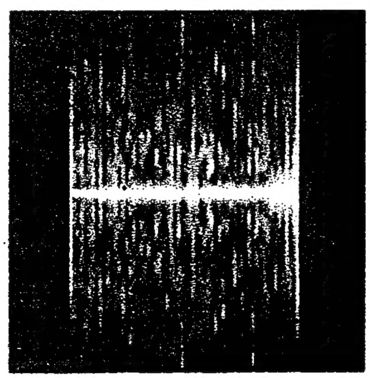


**As Viewed from ASI** ***(ivss1)***

**Speckle Image** ***(pcss1)***



**Auto-correlation** ***(pss1cor)***



**ASI Output Image** ***(pss1rcp)***

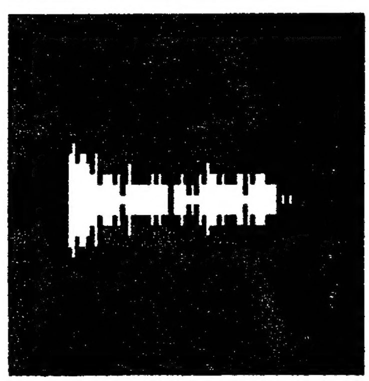
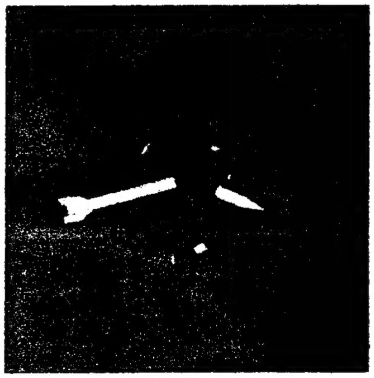
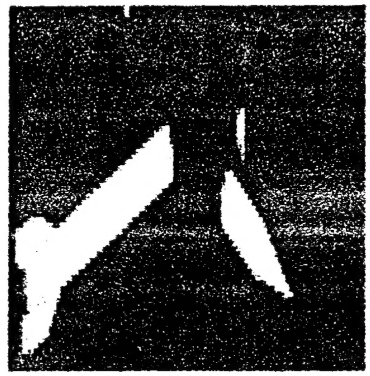


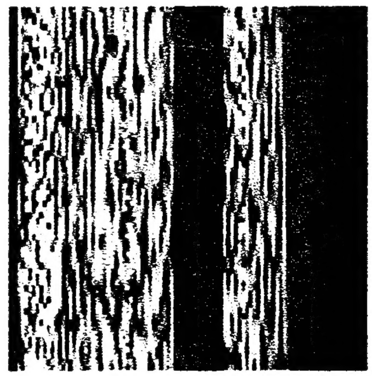
*Figure 8. Data and Reconstructed ASI Image Display for SS-1B (SCUD) Missile (See Table 1.)*



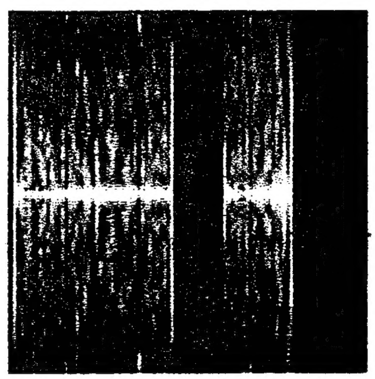
**Zoomed Out Image** *(ibrk1)*



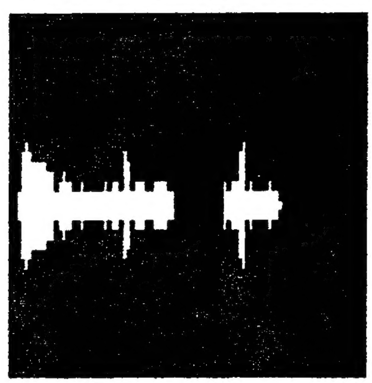
**As Viewed from ASI** *(ivcbrk1)*



**Speckle Image** *(pcbrk)*



**Auto-correlation** *(pbrkcor)*



**ASI Output Image** *(pbrkrcp)*

*Figure 9. Data and Reconstructed ASI Image Display for Damaged SS-1B (SCUD) Missile (See Table 1.)*

*Develop A Phase II Experimental Plan (SOW Item 4)*

The preliminary hardware design for an ASI field-demonstrable prototype was started this reporting period. Given the recent conclusion that the "missile hunter" configuration best utilizes ASI's features, the Phase II starwman hardware/demo designs are being based on this geometry. Key system parameters guiding the Phase II experiment design are shown in Table 2 below.

Key subsystems, like the laser, subaperture assembly, trasnmitter optics, etc. will require the widest use of commercial components to keep the cost and risk of a Phase II demonstration low. A survey of appropriate lasers, detectors and optical components was initiated. Also, an analysis of the transmit beam blurring due to atmospheric turbulence was initiated. Results from this task will receive the bulk of reporting attention next period.

*Table 2. Preliminary ASI Parameters Governing Phase II Experiment Design.*

| ***ASI Parameter*** | ***Prelim. Phase II Demo*** |
|---|---|
| Sensor Platform Altitude | 0 km (Sea Level) |
| Target Range | 50 km (54 naut. mi.) |
| 1-Way Atmos. Atten. | 0.65 ($\approx$ 8 km vis.) |
| Background Level | 30 W/m$^2$-$\mu$m-sr |
| Desired Resolution at Target | 10 cm (4") |
| Laser Wavelength | 1.54 $\mu$m |
| Max. Target Width | 2 m |
| Min. Target Width | 0.5 m |
| Target Reflectivity | 10% |
| Pre-Detector Photon # | 1000 (per subap.) |
| Number of Subapertures | 40 |
| Sub. Array Length, Width | 0.8 m x 0.4 m |
| Tran Aper. Length, Width | 0.8 m x 10 mm |
| Req'd 1-Pulse Energy (Calc) | $\approx$ 125 mJ |
| Req'd Pulse Rep. Frequency | $\approx$ 50 Hz |

*Manage Program, Conduct Reviews, Generate Reports (SOW Item 5)*

The following Task 5 accomplishments were completed this period:

- The APRIL 95 progress report was compiled.
- The MARCH 95 and APRIL 95 progress reports received a final edit and were mailed.
- The SPARTA subcontract activity was managed. Meetings were held with key SPARTA team members at SPARTA's facility every 7 -10 working days to monitor progress, provide technical input and guide target simulation activities in a relevant direction, based on evolving system analysis results.
- Draft final report materials were generated covering work completed to date.